

SCIENCE FOR GLASS PRODUCTION

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MONITORING THE STRESSED STATE OF STRUCTURAL GLASS BLOCKS

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Based on a polariscope/polarimeter a device for monitoring residual stresses in structural glass blocks is developed that makes it possible to automate the measurement of residual stresses and eliminate the negative effect of the light-diffusing glass-block coating on the interference pattern of the residual-stress distribution in assessing the stressed state of glass articles using the polarization-optical method.

The quality of structural glass blocks depends on the level of the residual stresses in them. However, use of the photoelasticity method [1, 2] in the measurement of the stressed state in structural glass blocks is accompanied by substantial difficulties, since this type of glass product has a light-diffusing notch on its inner surface that significantly distorts the interference pattern observed through a polariscope/polarimeter and makes precise measurement of stresses in a glass block employing a standard polariscope/polarimeter impossible (Fig. 1).

The authors suggest a device for measuring stresses in structural glass blocks (Fig. 2) that is free of the indicated shortcoming. This polariscope/polarimeter is equipped with a digital camera and a microcomputer. The coupling of the digital camera and the microcomputer presents no difficulties if devices with standard interfaces are used. For instance, a Kodak DCS 200 digital camera is linked to an IBM PC microcomputer via an SCSI interface. The digital camera transmits a digital image of the glass block to the microcomputer in the form of a standard graphic format file, which is subjected to two-dimensional digital filtration. The corrected image of the glass article is displayed on the computer monitor.

When the polariscope/polarimeter is used as a polarimeter, the digital image is a matrix of size $M \times M$:

$$\begin{bmatrix} x[1, 1] & \dots & x[1, M] \\ \dots & \dots & \dots \\ x[M, 1] & \dots & x[M, M] \end{bmatrix}.$$

The size of the matrix is determined by the resolving capacity of the scanner, and the elements are integer numbers

in the range $[0; 256]$ and correspond to the degree of luminance of the image points in gradations of gray (TIF format). If the stressed state is monitored in the polariscope mode (the stress values are inferred from the interference-pattern color), then prior to digital filtration the scanned glass-block image has to be decomposed into three matrices of size $M \times M$, so that the elements of each matrix correspond to the luminance of the points of the article image in the red, green, and blue ranges (RGB format), and filtration is implemented over each of the three independent chromaticity channels.

A two-dimensional array of points $x[n_1, n_2]$, $n_1 = 1, 2, \dots, M$, $n_2 = 1, 2, \dots, M$ is input in the digital filter of the microcomputer. Using the discrete Fourier transformation, the spectrum of the initial image of the glass block is calculated:

$$X[k_1, k_2] = \sum_{n_1=1}^M \sum_{n_2=1}^M x[n_1, n_2] \exp\left(-\frac{2\pi j}{M}((n_1-1)k_1 + (n_2-1)k_2)\right),$$

$$k_1 = 1, 2, \dots, M, \quad k_2 = 1, 2, \dots, M.$$

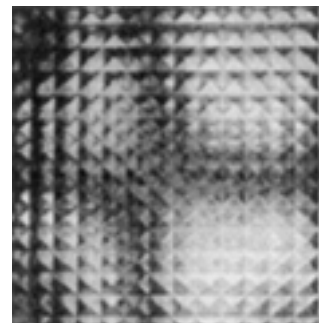


Fig. 1. Image of a BK 194/60 structural glass block on a polariscope/polarimeter display.

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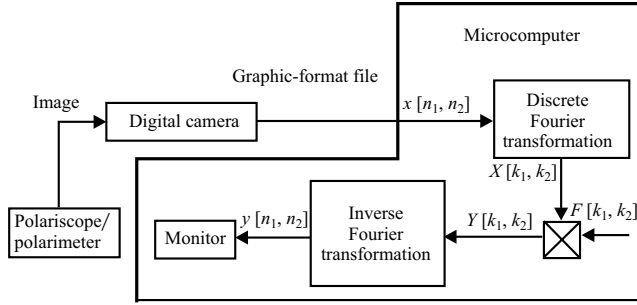


Fig. 2. Device for measuring stresses in a glass block: $x[n_1, n_2]$ discrete input signal; $X[k_1, k_2]$ input-signal spectrum; $F[k_1, k_2]$ frequency response of the filter; $Y[k_1, k_2]$ output signal spectrum; $y[n_1, n_2]$ two-dimensional discrete output signal.

The spectrum of the initial image of the glass block and the spectral characteristic of the digital filter $F[k_1, k_2]$ are multiplied componentwise:

$$Y[k_1, k_2] = X[k_1, k_2] F[k_1, k_2], \\ k_1 = 1, 2, \dots, M, \quad k_2 = 1, 2, \dots, M.$$

The spectrum of the processed image of the glass block $Y[k_1, k_2]$ is subjected to the inverse Fourier transformation:

$$y[n_1, n_2] = \frac{1}{M^2} \sum_{k_1=1}^M \sum_{k_2=1}^M Y[k_1, k_2] \times \\ \exp\left(\frac{2\pi j}{M}((k_1-1)n_1 + (k_2-1)n_2)\right),$$

as a result of which the image of the glass block on the microcomputer display is obtained.

The spectral characteristic of the digital filter $F[k_1, k_2]$ depends on the geometrical configuration of the light-diffusing notch on the glass-block surface and is determined in the following way using the window method [3]:

– the number of points contained in a period of repetition of the light-diffusing faces along the horizontal axis P_1 and the vertical axis P_2 on the scanned image of the article is determined;

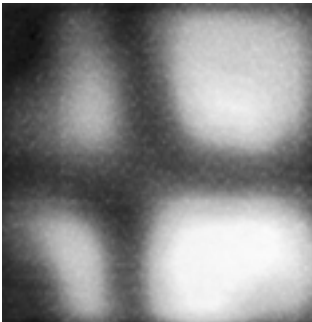


Fig. 3. Image of a BK 194/60 glass block in polarized light processed by a two-dimensional digital filter.

– the perfect spectral characteristic of the filter is set:

$$I_f[k_1, k_2] = \begin{cases} 1, & (k_1 \in \{1, 2, \dots, P_1\}) \wedge (k_2 \in \{1, 2, \dots, P_2\}), \\ 0, & (k_1 \notin \{1, 2, \dots, P_1\}) \vee (k_2 \notin \{1, 2, \dots, P_2\}), \end{cases} \\ k_1 = 1, 2, \dots, M, \quad k_2 = 1, 2, \dots, M;$$

– the pulse response of the perfect filter is calculated:

$$i_f[n_1, n_2] = \frac{1}{M^2} \sum_{k_1=1}^M \sum_{k_2=1}^M I_f[k_1, k_2] \times \\ \exp\left(\frac{2\pi j}{M}((k_1-1)n_1 + (k_2-1)n_2)\right), \\ n_1 = 1, 2, \dots, M, \quad n_2 = 1, 2, \dots, M;$$

– the window function is set:

$$w[n_1, n_2] = \begin{cases} 1, & (n_1 \in \{1, 2, \dots, Q_1\}) \wedge (n_2 \in \{1, 2, \dots, Q_2\}), \\ 0, & (n_1 \notin \{1, 2, \dots, Q_1\}) \vee (n_2 \notin \{1, 2, \dots, Q_2\}), \end{cases} \\ n_1 = 1, 2, \dots, M, \quad n_2 = 1, 2, \dots, M,$$

where the window size $Q_1 \times Q_2$, $1 < Q_1 < M$, $1 < Q_2 < M$ is equal to the number of points of the spectral characteristic of the actual digital filter (the order of the filter) and is selected based on the required rate and quality of image processing (the experiments performed by the authors showed that a 10×10 point filter is sufficient);

– the pulse response of the actual filter is calculated:

$$f[n_1, n_2] = i_f[n_1, n_2] w[n_1, n_2], \\ n_1 = 1, 2, \dots, M, \quad n_2 = 1, 2, \dots, M;$$

– the spectral characteristic of the actual filter is calculated:

$$F[k_1, k_2] = \sum_{n_1=1}^M \sum_{n_2=1}^M f[n_1, n_2] \times \\ \exp\left(-\frac{2\pi j}{M}((n_1-1)k_1 + (n_2-1)k_2)\right), \\ k_1 = 1, 2, \dots, M, \quad k_2 = 1, 2, \dots, M.$$

The proposed device makes it possible to eliminate the negative effect of the light-diffusing coating of the glass-block surfaces on the interference pattern of the stress distribution in measurements based on the polarization-optical method and thus makes it possible to adequately evaluate the stressed state of the glass article (Fig. 3).

When the quality of annealing is monitored by a polariscope/polarimeter, in both the polariscope and polarimeter modes, the subjective visual perception of the interference pattern by the operator has a negative effect on the accuracy of measurements. In the first case, it is necessary to register by turning the stage of the instrument the interference pattern color that correlates with the maximum difference in the path of the rays inside the sample according to a standard chroma-

ticity scale. In the second case it is necessary to register, by turning the analyzer, the moment of maximum darkening in the monitored areas of the sample [4]. In using the proposed device, the functions of monitoring and analysis of the interference pattern can be assigned to the microcomputer, which will improve the accuracy of measurements of residual stresses in glass products.

Practical application of the given device for measuring residual stresses in structural glass blocks will make it possible not only to increase the accuracy of the polarization-optical method of monitoring but also to automate the analysis of the stressed state of glass articles. The need for development of such automatic devices for monitoring residual stresses in glass articles arises due to implementation of energy-saving technologies [5] that require the development of automated control systems for the process of annealing glass

articles that provide stabilization of all process parameters (including the residual stresses in the products).

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